

## GIS-BASED HABITAT MODELS FOR MOUNTAIN GOATS

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We used logistic regression to develop habitat models from observation of mountain goats (*Oreamnos americanus*) in alpine habitats near Mt. Evans, Colorado. Mountain goats used areas near escape terrain, on moderate slopes, at midelevations, and on southerly exposures more than expected. Habitat models for summer, winter, or all-seasons correctly classified 81–83% of observations and incorrectly classified 12–13% of locations not used by mountain goats. A model based only on distance to escape terrain correctly classified 87% of observations and classified 38% of the study area as suitable habitat. Our models provide a way to use readily available data and simple techniques to quickly identify suitable habitat over large geographical areas.

Key words: escape terrain, geographical information system, habitat model, logistic regression, mountain goat, *Oreamonos americanus*

Mountain goats (*O. americanus*) are native to the northern Rocky Mountains, but translocations have established populations of mountain goats in areas where they may be an exotic species (Fitzgerald et al. 1994; Wigal and Coggins 1982). As mountain goat populations have the potential to increase rapidly, concerns exist that introduced mountain goat populations may cause habitat degradation or compete with native species. Mountain goats and native bighorn sheep (*Ovis canadensis*) in Colorado occur in broadly similar habitats, at similar elevations, and they consume many of the same forages (Fitzgerald et al. 1994; Laundré 1994). Thus, strong potential exists for competition between these species in Colorado (Gross 2001; Hobbs et al. 1990), heightening concerns that expanding mountain goat populations may displace or reduce the vigor of native sheep populations.

A key requirement for evaluating long-term effects of mountain goats on habitats or other species is a method for identifying the areas most likely to be inhabited and impacted by mountain goats. Efforts to evaluate impacts of mountain goats or to identify areas suitable for colonization have been hampered by the absence of a process for identifying suitable habitat from remotely sensed data. A habitat model is central to understanding the ecology of a species and to many decisions on management. In particular, this study was motivated by the need to evaluate the potential impacts of mountain goats on plants and animals in Rocky Mountain National Park as part of a process to formulate policy for management of goats in the park and elsewhere in Colorado. To meet this need, we analyzed observations of habitat use by mountain goats from the area near Mt. Evans, Colorado. Our goals were to determine whether hab-

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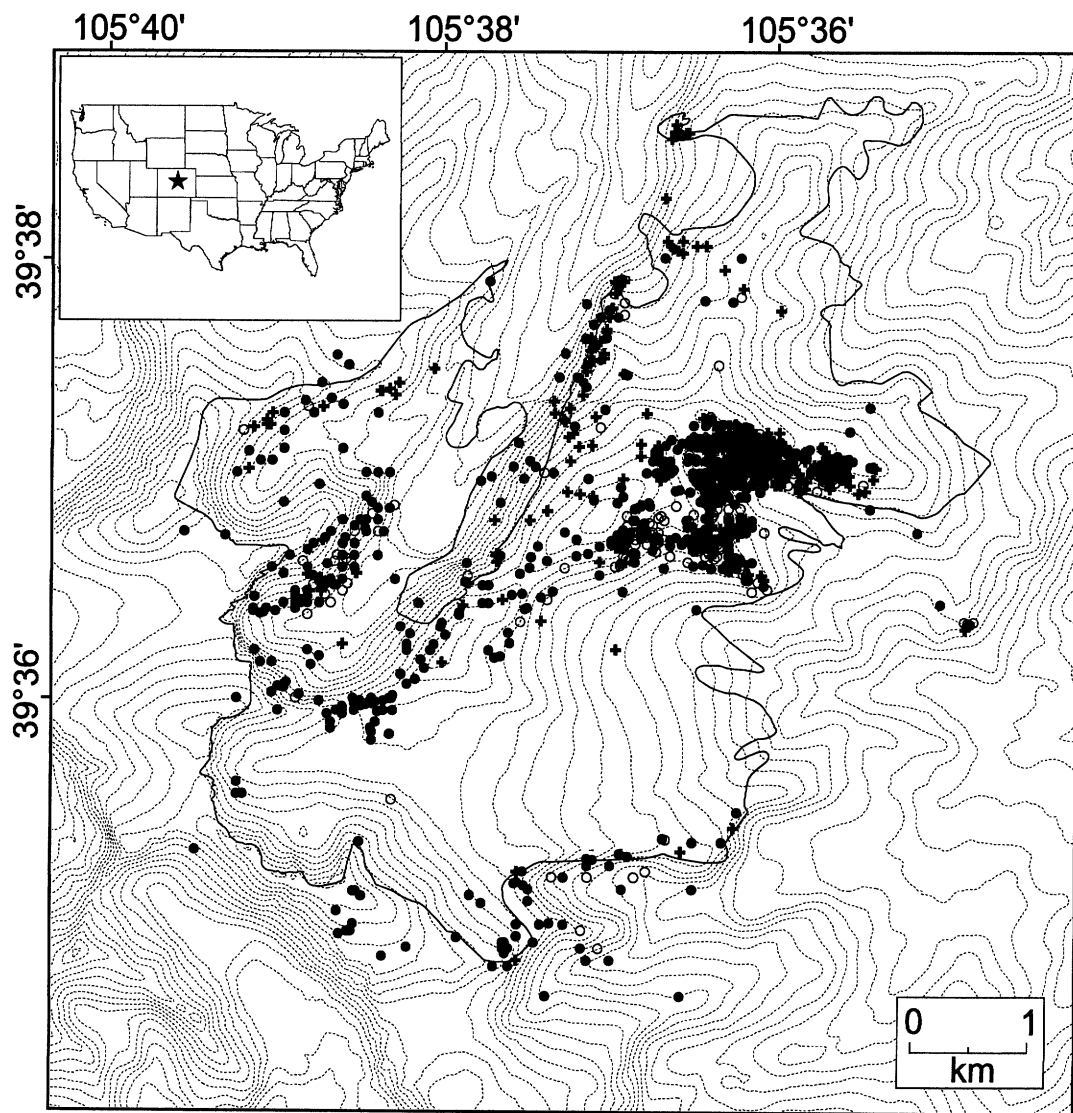


FIG. 1.—Map of the study area (outlined) near Mt. Evans, Colorado, with 40-m contour intervals. Symbols indicate locations where mountain goats were observed (● = summer, + = winter, ○ = other times).

itat use by mountain goats could be predicted from widely available GIS-based data and to evaluate seasonal differences in the intensity and spatial patterns of habitat use.

#### MATERIALS AND METHODS

*Study area and population.*—Our habitat models were based on observations of mountain goats in alpine and subalpine habitats at eleva-

tions of approximately 3,400–4,300 m, including several subsummits of approximately 4,000 m. The summit of Mt. Evans (4,340 m) was on the southwestern boundary of the study area (Fig. 1). The primary habitats consisted of alpine meadows, krummholz, wind-blown fellfields, scree slopes, subalpine forest, and cliffs. Dominant species in meadows included willows (*Salix*), sedges (*Carex*), grasses (*Poa*, *Koeleria macrantha*, etc.), and forbs (*Trifolium*, *Geum*; Braun 1969). Krummholz was composed of sub-

alpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and juniper (*Juniperus communis*—Braun 1969; Marr 1967). Habitat models were developed from observations of mountain goats in the area readily visible from the survey route.

The Mt. Evans mountain goat population was founded in 1961 through introduction of 15 individuals. The population subsequently exhibited a period of sustained growth and increased to at least 168 animals by 1983 (Reed and Green 1994). During the study period of 1981–1986, population counts conducted by the Colorado Division of Wildlife resulted in an estimated average minimum-number-alive of approximately 130 goats inhabiting an area of about 100 km<sup>2</sup> (Reed and Green 1994). About 15 goats were harvested from the population each year during the period of the study, and the population was thought to be relatively stable.

**Procedure.**—Observations were collected from weekly sightings over a 6-year period. A fixed 16.9-km survey route crossed the terrain at elevations of 3,460–4,040 m and permitted views of all slopes and aspects and of terrain that ranged from flat to vertical. The observer recorded (when possible) the sex, age, location, time, identifying marks, and activity of all mountain goats and bighorn sheep seen from the route. Animals were classified as kids, yearlings, adults, or unclassified (age and/or sex undetermined). Locations were determined by placing a gridded plastic overlay on a 1:24,000 topographical map and recording the Universal Transverse Mercator coordinates, rounding to the nearest 10 m. A single experienced observer (D. F. Reed) conducted all surveys. The survey route permitted clear views of hillsides, cliffs, and valleys in an area of approximately 23.5 km<sup>2</sup>. Each survey entailed approximately 6–8 h of observations.

Surveys were attempted at weekly intervals from June 1981 through June 1986, but some surveys were not completed during winter because bad weather limited visibility. Over the study period, 206 surveys were conducted. When habitat use is strongly correlated with topographic features or activity centers shift seasonally, it may not be possible to achieve a lag-time between samples that satisfies commonly used tests for independence (Minta 1992; Solow 1989; Swihart and Slade 1985, 1997). Most surveys (98%) followed the previous survey by  $\geq 4$  days, although inclement weather resulted in 5

surveys (2%) that either took 2 days to complete or that followed the previous survey by  $< 4$  days. Thus, observations were separated by more than 1 activity shift (defined as a period of high activity, followed by a period of low activity: Minta 1992), and we assumed that they represented biologically independent observations (Minta 1992). During the study period, 69 mountain goats were marked with collars that allowed recognition of individual animals.

**Data analysis and model development.**—We divided observations into biologically defined seasons of winter (November–April) and summer (June–September). Because of variations in weather, observations from May and October could not be assigned unambiguously to either summer or winter. Observations from these 2 months were therefore included only in analyses of all-seasons data. Because mountain goats rarely occur singly, and the individuals in a group do not represent independent samples, most analyses were conducted on the locations of groups rather than individuals. Observations of groups were classified to social classes of males, females and kids, mixed, or unclassified. From survey data, we calculated both arithmetic mean group size and typical group size (Gross et al. 1995; Jarman 1974). Typical group size accounts for variation in group size and is a better representation of the social environment experienced by the average animal. It is defined as

$$TGS = \frac{\sum_{i=1} n_i^2}{N}$$

where  $n$  is group size and  $N$  is the total number of animals in all  $i$  groups. Differences in the size of groups were evaluated by two-way analysis of variance, and mean values were compared by the Scheffé multiple-comparison procedure (Proc GLM—SAS Institute Inc. 2000).

We fitted multiple logistic regression models to topographic attributes of active (used) and inactive (unused) sites (Hosmer and Lemeshow 1989; Manly et al. 1993). As mountain goats are strongly associated with topographic features (Saunders 1955; Varley 1994), we developed the model using elevation (m), slope (degree), aspect (N–S and E–W), and distance to escape terrain as predictive variables. Topographic information was derived from a United States Geological Survey digital elevation map at 30-m resolution. Aspect and slope were calculated using

slope and aspect functions in ArcInfo GRID (ESRI 1999). Aspect was transformed into 2 continuous variables that described E–W and N–S exposures, with values from 0 to 180 where 0 = due E or N and 180 = due W or S.

Mountain goats are associated with steep terrain, which they use to escape from predators. Escape terrain has been described as steep slopes of broken, rocky terrain (Adams et al. 1982b; Smith et al. 1991; Varley 1994), but no consistent criteria exist for identifying escape terrain. Varley (1994) defined escape terrain for mountain goats as slopes  $>25^\circ$ , and Smith et al. (1991) and Johnson and Swift (2000) defined escape terrain for bighorn sheep as slopes  $>27^\circ$ . To define escape terrain, we used field observations to locate areas that goats appeared to use as escape terrain, and we then used ArcInfo (ESRI 1999) to determine the slope of these areas. Based on this partially subjective evaluation, we defined escape terrain for Colorado mountain goats as slopes  $\geq 33^\circ$ .

Model development required that we compare attributes of active sites to those of randomly selected inactive sites. Active sites consisted of points where mountain goats were observed. To create a set of inactive points for comparison, we first calculated the density of mountain goats in each 30-m pixel of the study area using a kernel density estimator (bandwidth = 100 m; Mathsoft, Inc. 1999; Silverman 1986). Mountain goat densities were estimated from observations of individual goats. Areas with an estimated density  $>0$  defined the spatial extent of areas used by mountain goats. Inactive sites were chosen from randomly selected coordinates in areas where the estimated density was 0.

Other habitat models have been developed and evaluated from data sets that contained highly variable ratios of active to inactive sites. In general, model precision is thought to be greater when models are developed from data that include a greater number of inactive sites than active sites, perhaps because most study sites contain more unsuitable than suitable habitat (Fielding and Haworth 1995; Kvamme 1985; Pereira and Itami 1991). The larger unsuitable area presumably includes more variation than the suitable area; therefore, more points are needed to characterize the unused area with the same degree of precision as the used area. To determine the appropriate ratio of active to inactive sites to be used in the models, we devel-

oped several trial models using ratios of active to inactive sites of 1:1, 1:2, and approximately 1:10. The best-fit trial model, signifying the most appropriate ratio of active to inactive sites, was selected by minimizing the Akaike Information Criteria (Akaike 1973; Burnham and Anderson 1998) and maximizing the coefficient of determination.

The predictive model for mountain goat habitat selection was created using the logistic regression equation where the probability of use of an active site ( $pr[x]$ ) is

$$pr(x) = \frac{\exp(\beta_0 + \beta_1 x_1 + \dots + \beta_n x_n)}{1 + \exp(\beta_0 + \beta_1 x_1 + \dots + \beta_n x_n)}$$

where  $x_1, \dots, x_n$  are independent predictor variables and  $\beta_0, \dots, \beta_n$  are logistic coefficients (Hosmer and Lemeshow 1989). Examination of the cumulative distribution function of slope and elevation of active sites showed that the function was curvilinear. We therefore included 2nd-order polynomials of these terms in the variable selection process (Neter et al. 1996).

The strong association of mountain goats with precipitous mountain terrain suggested that escape terrain could be the most important factor influencing habitat selection by mountain goats and that a model based on this feature alone might offer some predictive value (Fox 1983; von Elsner-Schack 1986). We developed a simple distance model using distance to escape terrain as the sole predictor of suitable habitat. We used a 2-step process to define the single model parameter. First, at each 1-m distance interval from escape terrain, we determined the proportion of active sites and the proportion of the entire study area that fell within the specified distance. We then classified the area within  $x$  m of escape terrain as suitable habitat, where  $x$  was the distance that maximized the difference between the proportion of active sites and proportion of habitat classified as suitable.

We tested the predictive ability of the models using 2 techniques. First, we used a standard procedure in classification analysis and separated observations into groups used for development and testing of the model (Beard et al. 1999; Devroye et al. 1996; Pereira and Itami 1991). For each season, we created 3 subsets of data for model development by randomly selecting 75% of the observations in the all-season, the summer, and the winter data sets. The remaining

TABLE 1.—Number of groups, typical group size (the size of group experienced by most animals), and mean group size of mountain goat groups observed during systematic surveys, by season. Group types are female and kid, mature males, mixed, and unclassified. Groups were considered unclassified when fewer than 70% of individuals were categorized by sex and age.

Season	Groups		Group size		
	Type	<i>n</i>	Typical	$\bar{X}$	<i>SD</i>
Summer	Female and kid	191	8.7	5.0	4.3
	Mature male	14	1.6	1.3	0.6
	Mixed	54	13.1	8.0	6.5
	Unclassified	114	12.0	5.2	6.0
	All	373	10.5	5.4	5.2
Winter	Female and kid	95	9.8	5.9	4.8
	Mature male	5	1.0	1.0	0.0
	Mixed	70	16.4	11.1	7.7
	Unclassified	143	15.3	8.8	7.6
	All	313	14.4	8.3	8.0
All year	Female and kid	347	8.8	5.1	4.4
	Mature male	28	1.4	1.2	0.5
	Mixed	138	15.3	9.9	7.3
	Unclassified	302	14.2	7.3	7.2
	All	815	12.6	6.6	6.3

25% of observations were withheld to test model results (Pereira and Itami 1991). We developed models from the 3 subsets for each data set and selected the best-fit model by comparing the coefficient of determination from each model fit.

As a 2nd test of the predictive ability of the model, we compared model results with independent observations of mountain goats from the study site (but not from the systematic surveys) and from adjacent areas. This data set consisted of 691 observations of mountain goat groups that were recorded during the period of study.

**Habitat model evaluation.**—We used classification error rates to evaluate fit of models. To calculate classification error rate, we compared output from the logistic regression models with a cutoff value. Based on this comparison, each 30 by 30-m pixel of the study area was categorized into a dichotomous 0–1 variable that represented unsuitable and suitable habitat. The cutoff value was selected to maximize the difference between the proportion of correctly classified active sites and the proportion of incorrectly classified inactive sites (Pereira and Itami 1991). This process determined the tradeoff between maximizing correct classification of active sites (by selecting a lower cutoff value) and minimizing the number of inactive sites classified as suitable (by selecting a higher cutoff value). We

calculated 2 types of classification error rates. First, we compared the proportion of correctly classified active sites to the proportion of incorrectly classified inactive sites. Second, we compared the proportion of correctly classified active sites to the proportion of the study area classified as suitable. Under a random spatial model, the proportion of inactive sites incorrectly classified as suitable would equal the proportion of the study area classified as suitable.

## RESULTS

The data set for model development consisted of 815 groups of mountain goats that included sightings of 5,343 individuals (Fig. 1). Average group size in summer (5.4) was smaller than in winter (8.3;  $F = 40.8$ ,  $d.f. = 3, 678$ ,  $P < 0.001$ ; Table 1). Large differences between typical group size and average group size indicated that distributions of sizes were skewed toward large groups. Group size varied with composition ( $F = 16.4$ ,  $d.f. = 3, 678$ ,  $P < 0.001$ ; Table 1). Mature male groups typically composed of 1 or 2 males were smaller (Scheffé's test;  $P < 0.05$ ,  $d.f. = 3, 678$ ) than other group types, and mixed groups were larger than other groups ( $P < 0.05$ ,  $d.f. =$

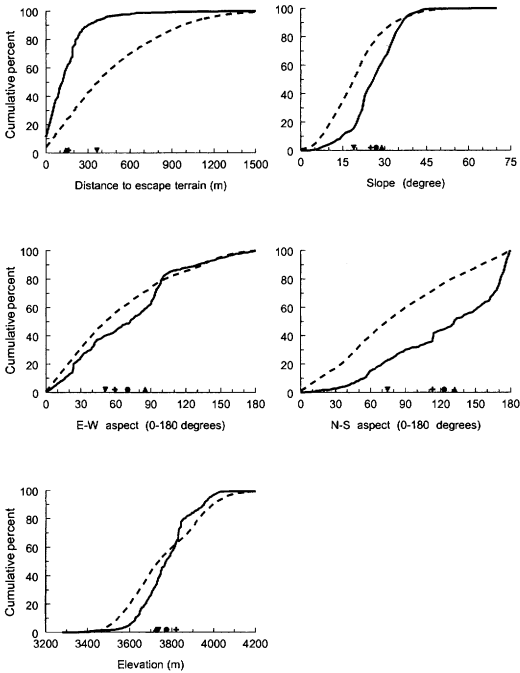


FIG. 2.—Cumulative frequency distributions of independent variables used for model development for the entire study area near Mt. Evans, Colorado (broken lines) and locations where mountain goats were observed (solid lines;  $n = 815$  locations). Mean values for observations are indicated on the horizontal axis for the entire study ( $\nabla$ ), the winter habitat ( $\blacktriangle$ ), summer model ( $+$ ), and all-seasons model ( $\bullet$ ).

3, 678). However, we observed few mature male groups ( $<4\%$  of observations during any season), and mixed groups were composed primarily of females and kids and

were thus similar to female–kid groups. Therefore, we weighted each group equally in the analyses. If habitat selection differed between group types, equal weighting of each group may have slightly biased results toward group types with smaller sizes. Sample sizes were too small to evaluate any effect of group type.

We observed little difference in the estimated regression coefficients between models developed using different ratios of active to inactive sites, but the coefficient of determination was consistently greatest for models developed from an equal number of active and inactive sites. We therefore used equal numbers of active and inactive sites for model development.

A comparison of attributes of active sites and the entire study area revealed differences in the distribution of predictor variables between areas used and those of the entire study area (Fig. 2). Mountain goats clearly selected sites that were closer to escape terrain, with an intermediate slope ( $\sim 20\text{--}50^\circ$ ) and at intermediate elevations within the study site (Figs. 1 and 2).

Model coefficients differed among models, especially between the summer and other models (Table 2). Predicted habitat suitability increased with proximity to escape terrain and with southern exposure (Table 2; Fig. 2). The effects of elevation and slope were represented by positive coefficients, whereas coefficients for the squares

TABLE 2.—Multiple logistic regression coefficients for mountain goat habitat suitability models developed from observations of mountain goats near Mt. Evans, Colorado.

	Model					
	All seasons		Summer		Winter	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant ( $\times 10^2$ )	−2.3610	0.428	−6.0669	1.078	−2.5376	0.694
Distance to escape terrain ( $\times 10^{-3}$ )	−5.9364	0.498	−8.3823	0.924	−4.3002	0.706
Slope	0.19812	0.032	0.29156	0.059	0.25602	0.059
Slope <sup>2</sup> ( $\times 10^{-3}$ )	−3.6523	0.612	−6.2110	1.153	−4.4135	1.150
Elevation	0.12501	0.023	0.31509	0.057	0.13573	0.037
Elevation <sup>2</sup> ( $\times 10^{-5}$ )	−1.6663	0.300	−4.0973	0.739	−1.8426	0.495
N–S aspect ( $\times 10^{-2}$ )	1.4376	0.167	1.0715	0.258	1.5007	0.0027
E–W aspect ( $\times 10^{-2}$ )	ns		ns		1.1340	0.308

TABLE 3.—Optimal cutoff values, classification rates, and relative performance of models for mountain goat habitat developed from multiple logistic regression and distance to escape terrain.

Model	Cutoff value	% of sites classified as suitable			Improvement over random (%)
		Active	Inactive	Total area	
All seasons logistic	0.64	81	13	22	59
Summer logistic	0.63	83	13	23	60
Winter logistic	0.59	82	12	20	62
Distance to escape terrain	258 m	87		37	50

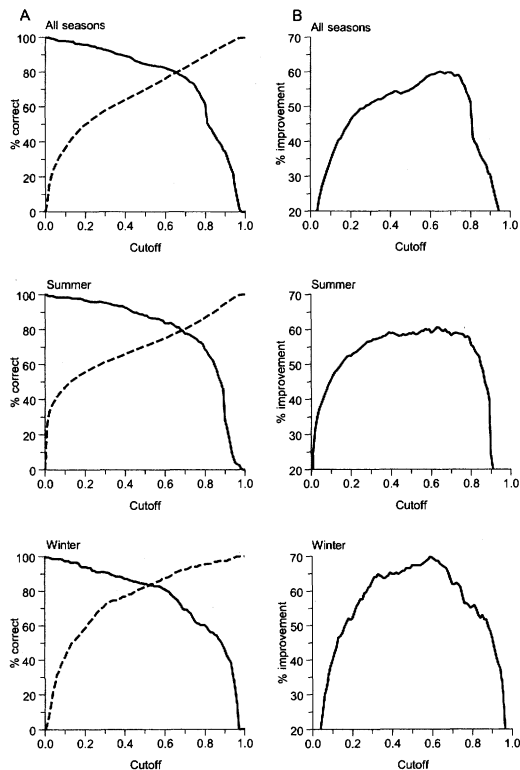


FIG. 3.—A) Classification error rates (% of pixels correctly classified) of habitat models for mountain goats near Mt. Evans, Colorado. Cutoff values were compared with predictions from logistic regression models and determined whether a pixel was categorized as suitable habitat. Lines show error rates for active sites (solid line) and inactive sites (broken line). B) Improvement of model predictions over a random spatial model for all cutoff values between suitable and unsuitable habitat.

of elevation and slope were negative, indicating that habitat use by mountain goats was most strongly associated with midelevations and intermediate slopes.

The optimal cutoff value for outputs of the logistic regression models, which distinguished suitable from unsuitable habitat, was 0.64 for the all-season model, 0.63 for the summer model, and 0.59 for the winter model (Table 3; Fig. 3). Classification of the study area into suitable and unsuitable habitat based on the all-season optimal cutoff value resulted in correct classification of 81% of active sites while including only 22% of the total area as suitable habitat, an improvement of 59% over a random model. All logistic models exhibited very low classification error rates for inactive sites (12–13%; Table 3). Classification rates of other seasonal models were similar (Table 3; Fig. 3). Model results were highly insensitive to changes in the cutoff value (Fig. 3), suggesting there were sharp distinctions between areas used and not used by mountain goats. The all-season, summer, and winter models correctly classified 80%, 78%, and 87% of nonsurvey observations ( $n = 691$ , 439, and 141, respectively). Areas classified as suitable by the 3 logistic models exhibited substantial overlap, varying from 71% overlap in habitat classified by the summer and winter models, to 83% overlap in predictions from the all-season model with predictions from the winter and summer models.

For the distance model, we categorized habitat  $\leq 258$  m from escape terrain as suit-

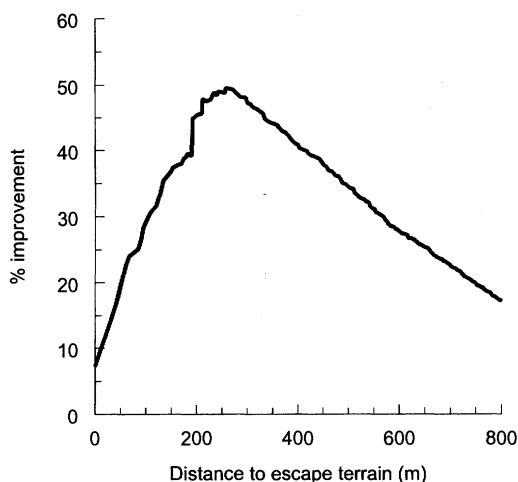


FIG. 4.—Improvement in classification rate of a mountain goat habitat model relying only on distance from escape terrain when compared with a random spatial model. The greatest improvement occurs at 258 m, the optimal cutoff distance.

able for mountain goats (Table 3; Figs. 4 and 5). The distance model correctly classified 87% of active sites and classified 37% of the study area as suitable habitat. This classification represented a 2-fold or 50% improvement over the random model.

#### DISCUSSION

Our models provide a simple process using readily available software for identifying habitat suitable for mountain goats in the southern Rocky Mountains. The predictive abilities of the habitat models (>80% correct classification of active sites) and classification error rates compared favorably with models for other species that required information far more difficult and expensive to obtain (Nadeau et al. 1995; Ozesmi and Mitsch 1997; Pereira and Itami 1991). A huge benefit of our models is a reliance on data that, for the United States, can usually be obtained from the Internet without cost. Development of habitat models that rely on simple procedures and inexpensive data are likely to be limited to species that are strongly associated with specific features that are readily captured by

remotely-sensed data. The strong affiliation of mountain goats with escape terrain exemplifies this characteristic.

We were surprised at the close correspondence of results from the logistic regression analysis and the distance model. Both types of models exhibited a significant improvement over random in identifying suitable habitat, but the parsimony of the distance model is a strong incentive for its application. Although escape terrain is known to be important in predicting the distribution of mountain goat populations, Adams and Bailey (1982) hypothesized that mountain goats in Colorado may be less restricted to areas near escape terrain than populations in the northern Rocky Mountains or further west. Colorado supports a lower density of predators than areas in the northern Rocky Mountains, and the lower risk of predation could result in a reduced association of mountain goats with escape terrain. Where predators are more abundant, most observations of mountain goats were reported within close proximity to cliffs (Fox and Streveler 1986; Singer and Doherty 1985; Varley 1996). When in large groups, mountain goats in Colorado have been observed more than 1 km from escape terrain (Adams et al. 1982a; Hopkins 1992). The large buffer around escape terrain that we identified is consistent with these observations; mountain goats were far more common near cliffs, but some observations were almost 1 km from areas we identified as escape terrain.

Observations used to build the habitat models were from high-elevation areas, but mountain goats may use lower elevation sites that offer good visibility and close proximity to escape terrain (Brandborg 1955; Fox and Streveler 1986; Rideout 1974; Smith 1976). Our observations were limited to alpine and subalpine habitats and we were unable to evaluate the use of lower elevation areas, although we suspect that goats rarely occupy forested habitats in Colorado. Application of the logistic models to areas where treeline occurs at a lower



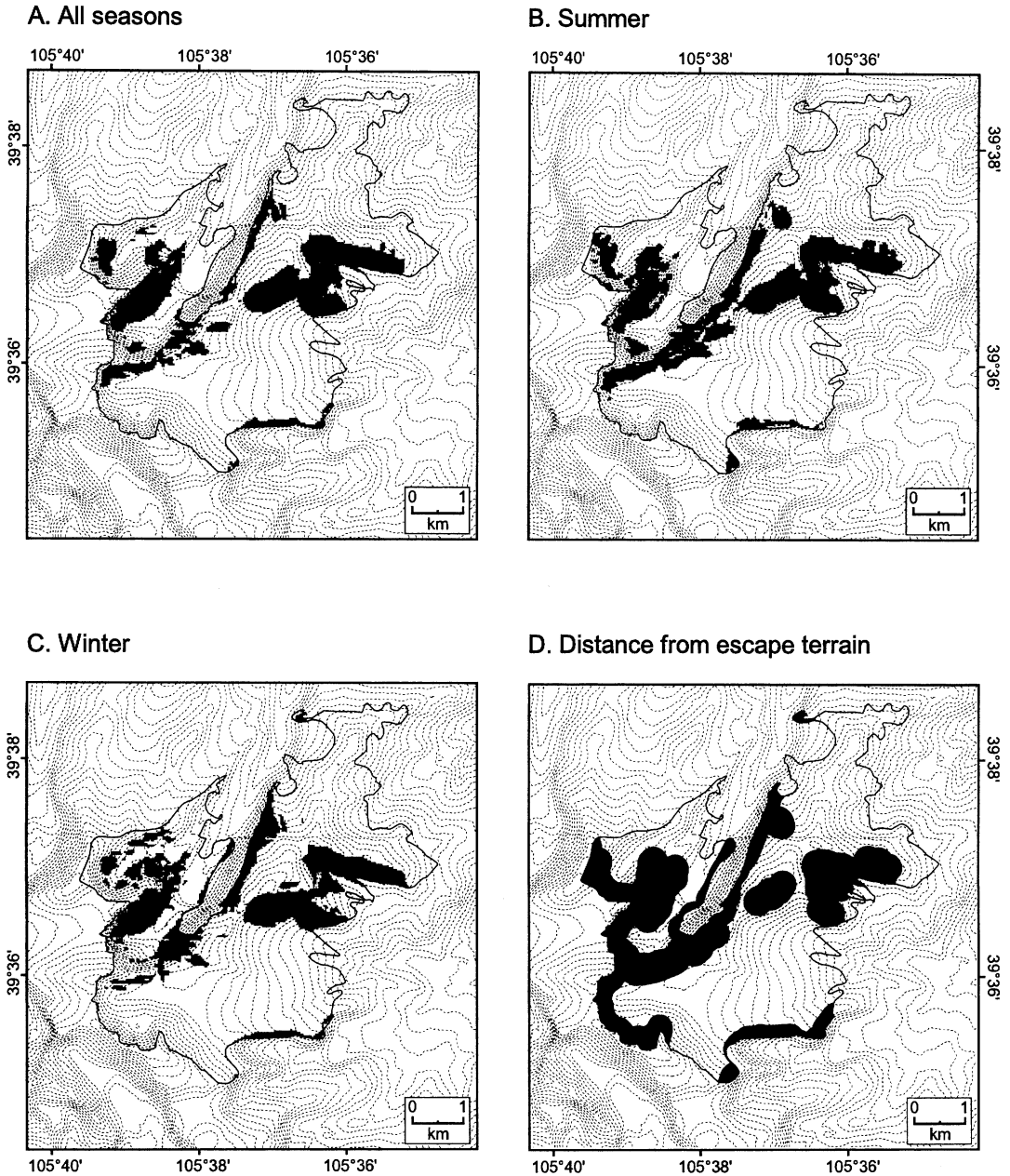


FIG. 5.—Distribution of suitable habitat for mountain goats (dark areas) in the vicinity of Mt. Evans, Colorado identified by logistic regression models. The study area is outlined, as in Fig. 1. Contour interval is 40 m.

elevation will likely require modification of the coefficients that account for effects of elevation.

Our results showed little difference between summer and winter habitat used by

mountain goats. Some previous studies concluded that winter ranges of mountain goats were frequently at lower elevations than summer ranges (Adams and Bailey 1982; Brandborg 1955; Smith 1976; Wigal and

Coggins 1982), or, if goats were at a high elevation, they preferred wind-swept slopes with minimal snow accumulation (Fox 1983; Rideout 1974; Rideout and Hoffman 1975). Summer home ranges of mountain goats are typically much larger than winter home ranges (Adams et al. 1982a; Hibbs 1966; L. D. Hibbs and F. A. Glover, in litt.), and we expected that the areas used in summer and winter would reflect previous observations. Model results were consistent with observations that mountain goats use a smaller area during winter, but we observed broad overlap in areas used during summer and winter. In winter, 20% of the study area was classified as suitable habitat, compared with 23% in summer, the season in which mountain goats were most dispersed. About 70% of the winter range overlapped with summer range, suggesting that during winter mountain goats occur at higher density and tend to use areas with slightly different characteristics.

The habitat models for mountain goats described here provide a simple and inexpensive method for quickly locating suitable habitat over large geographical areas. These models appear to have a high predictive value, largely because mountain goats have a strong association with prominent geographic features.

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